(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 264 651 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
11.12.2002 Bulletin 2002/50

(51) Int Cl.7: **B22D 27/02**, B22D 27/08

(21) Application number: 02252992.9

(22) Date of filing: 26.04.2002

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 26.04.2001 JP 2001128634

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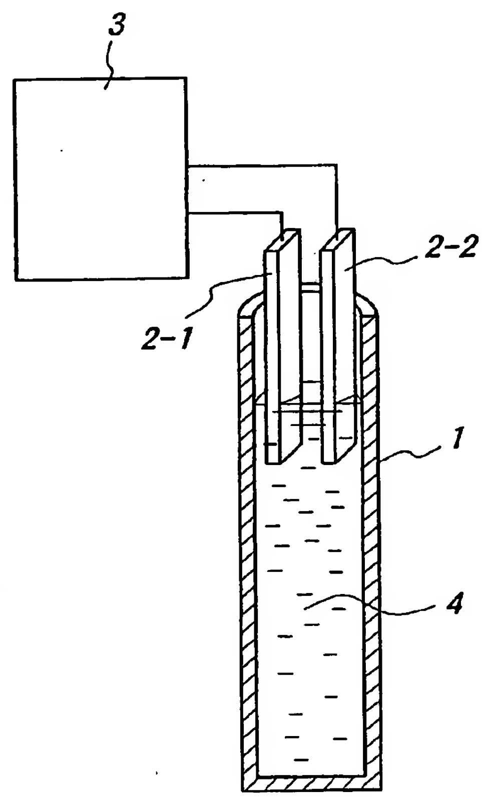
(54) Method for propagating vibration into a conductive fluid and method for solidifying a melted metal using the same propagating method of vibration

(57) A given static magnetic field and a given wave are applied to a conductive fluid so as to satisfy the equation of:

$$2\pi f<(\sigma/\rho)B^2 \qquad (1)$$

(f: the frequency (Hz) of the wave to be applied, σ: the electric conductivity (S/m) of the conductive fluid, ρ: the density (kg/m^3) of the conductive fluid, B: the strength of the static magnetic field (T) to be applied), thereby to generate and propagate a given vibration into the conductive fluid.

FIG. 1



EP 1 264 651 A2

Description

Background of the Invention

Field of the Invention

[0001] This invention relates to a method for propagating vibration into a conductive fluid and a method for solidifying a melted metal using the same propagating method of vibration.

Description of the prior art

[0002] The control of solidification structure and the refinement can be performed effectively by imparting vibration into the melted liquid metal to be solidified. For example, it is well known that solidification process is started by imparting mechanical impact to a supercooled liquid metal. It is also well known that fine structure can be created by imparting vibration to a melted liquid metal during solidification and degasifying process is promoted by applying compressional wave to a melted liquid metal.

[0003] On laboratory scale, by imparting a given mechanical vibration to the whole of a vessel where a liquid metal is charged, a given vibration can be easily imparted to the liquid metal. On large industrial scale, however, it is difficult to vibrate the whole of a huge vessel mechanically. Therefore, as of now, such an attempt is made as to position a magnetostrictive oscillator or an electrostrictive oscillator in a liquid metal, and thus, impart a given vibration to the liquid metal. Also, such an attempt is made as to introduce a compressional wave which is generated by a speaker into a liquid metal and thus, impart a given vibration to the liquid metal.

[0004] However, if such a magnetostrictive oscillator or an electrostrictive oscillator is employed, it may be melted or destroyed in the liquid metal, to contaminate the liquid metal. Also, the amplitude of the vibration to be imparted is restricted due to the limitation of the output power level of the oscillator. Moreover, if such a compressional wave is employed, it may be reflected almost entirely at the boundary between the liquid metal and the environmental atmosphere, not to be imparted to the liquid metal because the acoustic resistance between the liquid metal and the environmental atmosphere is increased. As a result, a method for propagating vibration into a liquid metal is not be developed particularly on the large industrial scale, at present.

Summery of the Invention

[0005] It is an object of the present invention to provide a new method for propagating vibration into a liquid metal which is usable on a large industrial scale.

[0006] In order to achieve the above object, this invention relates to a method for propagating vibration into a conductive fluid, comprising the steps of:

preparing a given conductive fluid, and
applying a given static magnetic field and a given wave to the conductive fluid so as to satisfy the equation of:

$$2\pi f<(\sigma/\rho)B^2 \qquad (1)$$

(f: the frequency (Hz) of the wave to be applied, σ: the electric conductivity (S/m) of the conductive fluid, ρ: the density (kg/m^3) of the conductive fluid, B: the strength of the static magnetic field (T) to be applied), thereby to generate and propagate a given vibration into the conductive fluid.

[0007] The inventors had been intensely studied to achieve the above object. Then, they had conceived that by applying an electromagnetic force to a melted conductive fluid such as a liquid metal, instead of conventionally utilizing a mechanical vibration, an oscillator or a speaker, a given vibration is generated and propagated in the conductive fluid.

[0008] From the past, it is well known that only a compressional wave can be propagated into a conductive fluid such as a liquid metal. On the other hand, the vibration originated from the electromagnetic force is a transverse wave. Therefore, in the present invention, the transverse wave is generated and propagated in the conductive fluid, to impart a given vibration to the conductive fluid. As mentioned above, since it is known that only a compressional wave can be propagated into the conductive fluid, the inventors had intensely studied to generate and propagate a transverse wave originated from the electromagnetic force.

[0009] If a static magnetic field of relatively large strength is applied to a conductive fluid, a given disturbance of magnetic field is generated due to the static magnetic field to be applied, and then, propagated in convection. That is, if the conductive fluid is moved under the static magnetic field, an inductive current is generated and thus, the distribution of the static magnetic field to be applied is changed. In this case, the conductive fluid is moved as the magnetic flux lines are attached to the fluid particles.

[0010] Then, the inventors found out that by applying the static magnetic field and a given wave to the conductive fluid under the above-mentioned condition so that a given requirement is satisfied, a transverse wave can be generated and propagated into the conductive fluid. As a result, a given vibration can be generated and propagated in the conductive fluid by the electromagnetic force. This invention is realized on the vast researches and developments as mentioned above.

[0011] According to the propagating method of vibration, a given vibration is generated in a conductive fluid by a given electromagnetic force originated from a static magnetic field and a wave. Therefore, without a large-

scale apparatus, the vibration can be easily generated in the conductive fluid. In this point of view, the propagating method of the present invention can be preferably employed on a large industrial scale.

[0012] For example, the propagating method of the present invention can be preferably utilized for solidifying a melted liquid metal. In this case, a given static magnetic field and a given wave are applied to the liquid metal during the solidification process so as to satisfy the above-requirement according to the present invention. In this case, the size of the solidification structure can be controlled unrestrainedly, and thus, the solidification structure can be easily fined.

Brief Description of the Drawings

[0013] For better understanding of the present invention, reference is made to the attached drawings, wherein

Fig. 1 is a schematic view showing an apparatus which is employed for solidifying a SnPb alloy according to the propagating method of vibration of the present invention.

Description of the Preferred Embodiments

[0014] This invention will be described in detail with reference to the accompanying drawings. In the present invention, it is required that a given static magnetic field and a given wave are applied to a conductive fluid so as to satisfy the above equation (1). Only if the equation (1) is satisfied, the kind of wave and the frequency of wave are not restricted. In a real process such as the solidification of a liquid metal, however, since the electric conductivity of the liquid metal is within a range of 10^5-10^7S/m and the density of the liquid metal is within a range of 10^3-10^4 kg/m^3, the equation (1) is satisfied by applying a static magnetic field having a strength within a range of several Tesla through several ten Tesla and applying a wave having a frequency within a range of several hundred Hz through several thousand Hz. For example the magnetic field strength may be in the ragne 2 to 50 T and the frequency of the wave may be in the range 100 to 5000 Hz.

[0015] In this case, a given disturbance of magnetic field is generated due to the static magnetic field to be applied and propagated in convention in the conductive fluid. That is, the distribution of magnetic field is determined by the convection. Therefore, a given transverse wave is generated and propagated in the conductive fluid, originated from the magnetic force of the static magnetic field and the wave, as mentioned above. As a result, a given vibration can be generated and propagated in the conductive fluid, originated from the transverse wave.

[0016] Such a static magnetic field can be generated from a super conductive magnet. Also, such a wave can be generated from a given external AC power supply. That is, an AC electric field from the external AC power supply can be utilized as the wave to be used in the present invention. In this way, the static magnetic field and the wave to be utilized in the present invention and satisfying the equation (1) can be easily obtained from the super conductive magnet and the external AC power supply, respectively.

[0017] The transverse wave generated in the conductive fluid when the equation (1) is satisfied is estimated as an Alfven wave. The Alfven wave is being intensely researched in astronomical physics and plasma engineering, but not almost done in industrial field. Therefore, the Alfven wave is not almost utilized in the industrial field. In view of the industrial use of the Alfven wave, too, the present invention is quite important.

[0018] The propagating method of vibration of the present invention can be employed for various industrial fields. Particularly, if the method is employed for solidifying a melted liquid metal, the solidification structure can be controlled freely, and then, fined. In addition, the method may be employed for degasification, promotion of refining reaction and control of solid-liquid boundary face configuration.

Example:

[0019] The example where the propagating method of vibration of the present invention is applied for solidifying a melted metal will be described in detail, hereinafter.

(Example)

[0020] In this example, such an apparatus as shown in Fig. 1 was employed, and an alloy having a composition of Sn-10mol%Pb (hereinafter, called as a "SnPb alloy") was melted and then, solidified. In the apparatus shown in Fig. 1, a cylindrical vessel 1 (internal diameter: 30 mm, height: 150 mm) made of glass is employed, and electrodes 2-1 and 2-2 (each width: 10 mm, each thickness: 2 mm) made of Cu are disposed in the vessel 1 so as to be opposite to one another. Also, an external AC power supply 3 is connected to the ends of the electrodes 2-1 and 2-2. The vessel 1 including the electrodes 2-1 and 2-2 is placed in a super conductive magnet (not shown).

[0021] A SnPb alloy 4 melted was charged in a depth of 120 mm in the vessel 1, and then, the electrodes 2-1 and 2-2 were immersed in the melted SnPb alloy 4 by a length of 20 mm, respectively. Then, a static magnetic field of a strength of 10T was applied from the super conductive magnet (not shown) and an AC electric field of a frequency of 200 Hz and an amplitude of 100A was applied from the external AC power supply 3 to the SnPb alloy 4. Since the electric conductivity of the SnPb alloy 4 is 10^6-10^7 S/m and the density ρ of the SnPb alloy 4 is about 10^4 kg/m^3, in this example, the above equation (1) is satisfied by the static magnetic field and the AC

electric field as mentioned above. Under the condition, the SnPb alloy 4 was solidified at a cooling rate of 0.1 K/sec.

[0022] When the solidification structure of the SnPb alloy solidified was observed, the size of the solidification structure was about 1 mm or below at both of the upper side and the lower side of the vessel 1.

[0023] When the pressure of a wave propagating in the melted SnPn alloy 4 was measured by a sensor provided at the bottom portion of the vessel 1, it was turned out to be almost proportion to the current value of the AC electric field applied from the external AC power supply 3. Therefore, during the above solidification process, it was turned out that a given Alfven wave was generated in the melted SnPb alloy 4, and it is estimated that the Alfven wave was propagated in the SnPb alloy 4.

(Comparative Example)

[0024] Except that the static magnetic field and the AC electric field were not applied and thus, a given wave which is estimated as the Alfven wave was not propagated, the melted SnPb alloy 4 was solidified in the same manner as Example. When the solidification structure of the SnPb alloy solidified was observed, the size of the solidification structure was roughed at both of the upper side and the lower side of the vessel 1. Particularly, at the lower side of the vessel 1, the size of the solidification structure was enlarged up to about several mm.

[0025] Although the present invention was described in detail with reference to the above examples, this invention is not limited to the above disclosure and every kind of variation and modification may be made without departing from the scope of the present invention.

[0026] As mentioned above, only by applying a given static magnetic field and a given electric field to a conductive fluid, according to the present invention, a given vibration can be generated and propagated in the conductive fluid without a large scale and complicated apparatus. Therefore, the propagating method of vibration of the present invention may be employed for various industrial fields, and for example, preferably as a solidification structure controlling method for a liquid metal melted.

Claims

1. A method for propagating vibration into a conductive fluid, comprising the steps of:

   preparing a given conductive fluid, and
   applying a given static magnetic field and a given wave to said conductive fluid so as to satisfy the equation of:

   $$2\pi f<(\sigma/\rho)B^2 \qquad (1)$$

   (f: the frequency (Hz) of the wave to be applied, σ: the electric conductivity (S/m) of the conductive fluid, ρ: the density (kg/m^3) of the conductive fluid, B: the strength of the static magnetic field (T) to be applied), thereby to generate and propagate a given vibration into said conductive fluid.

2. A propagating method as defined in claim 1, wherein said wave to be applied to said conductive fluid includes an AC electric field from an external AC power supply.

3. A propagating method as defined in claim 1 or 2, wherein a given disturbance of magnetic field is generated due to said static magnetic field to be applied and propagated in convection in said conductive fluid.

4. A propagating method as defined in any one of claims 1-3, wherein an Alfven wave is generated and propagated in said conductive fluid.

5. A method for solidifying a melted metal, comprising the steps of:

   preparing a melted metal, and
   applying a given static magnetic field and a given wave to said melted metal so as to satisfy the equation of:

   $$2\pi f<(\sigma/\rho)B^2 \qquad (1)$$

   (f: the frequency (Hz) of the wave to be applied, σ: the electric conductivity (S/m) of the conductive fluid, ρ: the density (kg/m^3) of the conductive fluid, B: the strength of the static magnetic field (T) to be applied), thereby to generate and propagate a given vibration into said melted metal.

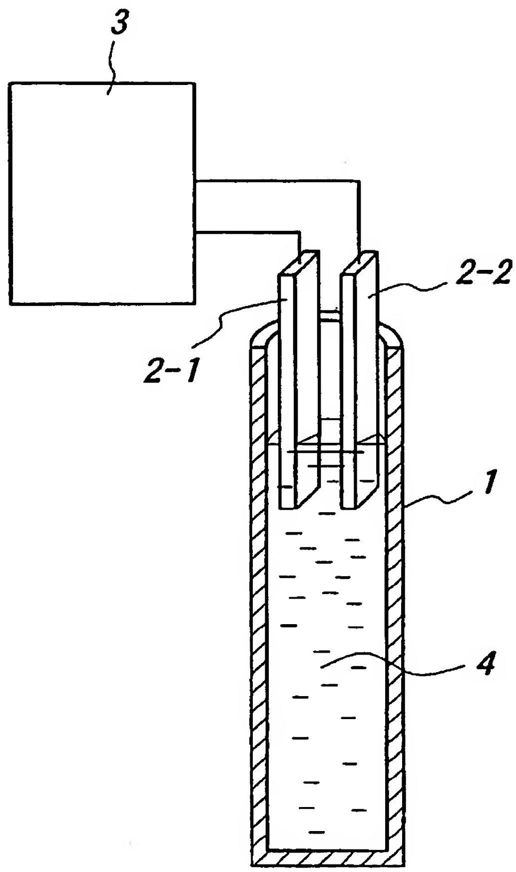
6. A solidifying method as defined in claim 5, wherein said wave to be applied to said melted metal includes an AC electric field from an external AC power supply.

7. A solidifying method as defined in claim 5 or 6, wherein a given disturbance of magnetic field is generated due to said static magnetic field to be applied and propagated in convection in said melted metal fluid.

8. A solidifying method as defined in any one of claims

5-7, wherein an Alfven wave is generated and propagated in said melted metal.

FIG. 1



(19) Europäisches Patentamt
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(11) EP 1 264 651 A3

(12) EUROPEAN PATENT APPLICATION

(88) Date of publication A3:
18.06.2003 Bulletin 2003/25

(43) Date of publication A2:
11.12.2002 Bulletin 2002/50

(21) Application number: 02252992.9

(22) Date of filing: 26.04.2002

(51) Int Cl.7: B22D 27/02, B22D 27/08

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 26.04.2001 JP 2001128634

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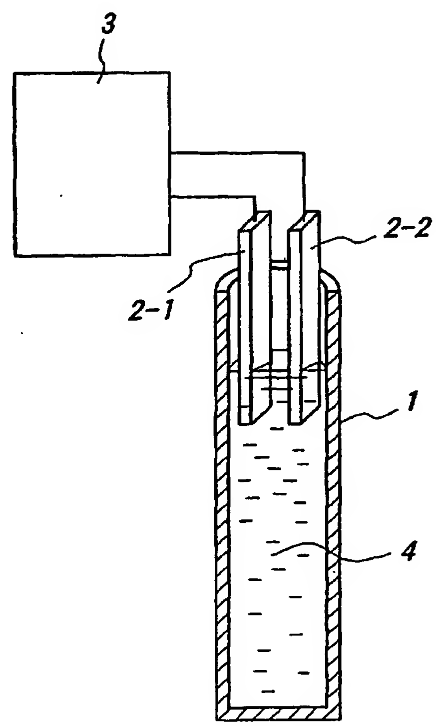
FIG. 1



EP 1 264 651 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 02 25 2992

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	25 March 2003	Baumgartner, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
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E : earlier patent document, but published on, or after the filing date
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EPO FORM 1503 03.82 (P04C01)

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EUROPEAN SEARCH REPORT

Application Number
EP 02 25 2992

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The present search report has been drawn up for all claims

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L : document cited for other reasons

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25-03-2003

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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 091 008 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
11.04.2001 Bulletin 2001/15

(51) Int. Cl.[7]: C22B 9/02, B22D 27/02

(21) Application number: 00109245.1

(22) Date of filing: 28.04.2000

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 05.10.1999 JP 28425699

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(54) Apparatus for generating compression waves in conductive liquid

(57) The invention intends to provide an apparatus for generating compression waves in a conductive liquid, which sufficiently enhances a strength of the compression waves by improving an ac electromagnetic force applying means that generates the compression waves directly in the conductive liquid contained in a vessel.

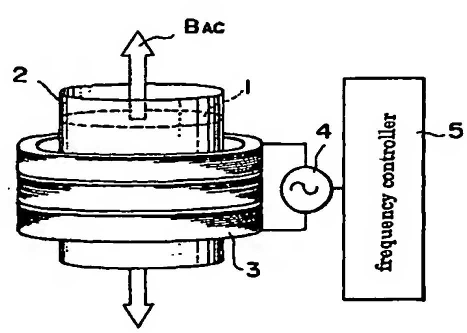
To accomplish the object, the apparatus of the invention comprises a vessel containing a conductive liquid such as a molten metal and an ac electromagnetic force applying means provided around the circumference of the vessel, which generates the compression waves in the conductive liquid contained in the vessel to thereby achieve material improvement after the solidification of the conductive liquid. The ac frequency f of the ac applying means is set within a range given by the following [expression 1], for a strong generation of the compression waves:

$$\frac{2}{L^2 \pi \mu \sigma} \le f \le \frac{c^2 \mu \sigma}{2\pi} \quad \text{[expression 1]}$$

here,

f: frequency (a major frequency when a wave-form of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)
L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
μ: permeability of the conductive liquid
σ: electric conductivity of the conductive liquid
c: propagation velocity of the compression waves in the conductive liquid.

FIG. I



Description

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to an apparatus for generating compression waves in a conductive liquid, such as a molten metal.

Description of the Related Art:

[0002] There have been poured intensive efforts in developing a technique that generates compression waves in a molten metal contained in a container and aims at an improvement of the tissues after the solidification of the molten metal and an enhancement of refining capabilities. However, it is considered difficult, at the present stage, to efficiently achieve a higher strength of the compression waves, and satisfactory results have not yet been accomplished.

[0003] Accordingly, it is an object of the invention to provide an apparatus for generating compression waves in a conductive liquid contained in a vessel, which improves an ac electromagnetic force applying means that generates the compression waves directly in the conductive liquid contained in the vessel, and thereby enhances the strength of the compression waves sufficiently.

[0004] In order to accomplish the foregoing object, the invention discloses an apparatus for generating compression waves in a conductive liquid, which comprises a vessel containing a conductive liquid and an ac electromagnetic force applying means that generates the compression waves in the conductive liquid contained in the vessel, in which an ac frequency f of the ac electromagnetic force applying means is set within a range given by the following [expression 1]:

$$\frac{2}{L^2\pi\mu\sigma} \leq f \leq \frac{c^2\mu\sigma}{2\pi} \qquad \text{[expression 1]}$$

Here,

- f: frequency (a major frequency when a wave-form of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)
- L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
- μ: permeability of the conductive liquid
- σ: electric conductivity of the conductive liquid
- c: propagation velocity of the compression waves in the conductive liquid

[0005] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the ac electromagnetic force applying means is an ac magnetic field generating electromagnetic coil, which is provided around the circumference of the vessel.

[0006] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which a dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel.

[0007] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel and the ac magnetic field generating electromagnetic coil are inserted in the bore of the superconducting magnet.

[0008] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the ac electromagnetic force applying means comprises a pair of electrodes that are installed at positions on the circumferential wall of the vessel facing to each other so as to energize the conductive liquid, and an ac power supply connected to the electrodes.

[0009] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel provided with the electrodes.

[0010] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel with a pair of the electrodes is inserted in the bore of the superconducting magnet.

[0011] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the vessel is formed of ceramics and provided with a metal reinforcing material on the circumference thereof, and an ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is provided overlying the vessel.

[0012] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel.

[0013] Further, the invention discloses an apparatus for generating compression waves in a conductive liquid, in which the dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel is inserted in the bore of the superconducting magnet.

[0014] According to the present invention relating to the aforementioned apparatus for generating compression waves in a conductive liquid, since the ac frequency of the ac electromagnetic force applying means that generates the compression waves in a conductive

liquid contained in a vessel is set within an appropriate range by the reason described later, the compression waves can be generated with a sufficient strength. Thereby, degassing of the conductive liquid and micro structuring of the tissues are effectively processed, and material improvement after the solidification of the conductive liquid will be brought about efficiently.

[0015] And, when the ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is installed around the circumference of the vessel, the compression waves will be generated in the conductive liquid with a simplified construction and a low cost.

[0016] And, when, in addition to the ac magnetic field generating electromagnetic coil, a dc magnetic field generating electromagnetic coil is further installed around the circumference of the vessel, the superimposition of both the electromagnetic coils effects a stronger generation of the compression waves in the conductive liquid contained in the vessel. Thereby, enhancement of the refining capabilities after the solidification of the conductive liquid and improvement of the tissues will sufficiently be accomplished.

[0017] Further, when, while the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, the foregoing vessel and the ac magnetic field generating electromagnetic coil are inserted in the bore of the superconducting magnet, the superimposition of both the dc magnetic field generating electromagnetic coil as the superconducting magnet and the ac magnetic field generating electromagnetic coil effects a still stronger generation of the compression waves in the conductive liquid contained in the vessel, and material improvement after the solidification of the conductive liquid is achieved still more efficiently.

[0018] Further, when the ac electromagnetic force applying means is made up with a pair of electrodes that are installed at positions on a circumferential wall of the vessel facing to each other so as to energize the conductive liquid in the vessel, and the ac power supply connected to the electrodes, and furthermore the dc magnetic field generating electromagnetic coil is installed around the circumference of the vessel, the ac magnetic field generating electromagnetic coil is not required. Accordingly, the total construction of the apparatus is simplified remarkably, and in addition, the compression waves are generated efficiently in the conductive liquid contained in the vessel so as to contribute to material improvement after the solidification of the liquid.

[0019] And, also in this case, when the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, in the bore of which is inserted the vessel with the electrodes, the effect of a strong electromagnetic force by the dc magnetic field generating electromagnetic coil as the superconducting magnet is superimposed on the effect by the ac electromagnetic force applying means by a pair of the electrodes, which generates the compression waves still more effectively in the conductive liquid contained in the vessel, thereby achieving material improvement after the solidification of the liquid.

[0020] Further, while the vessel maintains a sufficient strength reinforced by the metal reinforcing material, when it is provided with the ac magnetic field generating electromagnetic coil to overlie the vessel, the apparatus is able to generate intensified compression waves in the conductive liquid contained in the vessel without being influenced by the metal reinforcing material. Thus, degassing of the conductive liquid and micro structuring of the tissues are effectively processed, whereby material improvement after the solidification of the conductive liquid will be accomplished.

[0021] Further, when the superimposition effect by the ac magnetic field generating electromagnetic coil provided overlying the vessel and the dc magnetic field generating electromagnetic coil provided around the circumference of the vessel is configured to generate intensified compression waves in the conductive liquid contained in the vessel, the material improvement after the solidification of the conductive liquid will be achieved more appropriately.

[0022] And, when the dc magnetic field generating electromagnetic coil provided around the circumference of the vessel is made up with a superconducting coil in pursuit for the superimposition effect by association with the ac magnetic field generating electromagnetic coil provided overlying the vessel, a still stronger generation of the compression waves in the conductive liquid contained in the vessel will be brought about, and a sufficient material improvement after the solidification of the liquid will be accomplished.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023]

Fig. 1 is a perspective view to typically illustrate an apparatus for generating compression waves in a conductive liquid as a first embodiment of the present invention;

Fig. 2 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a second embodiment of the invention;

Fig. 3 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a third embodiment of the invention;

Fig. 4 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a fourth embodiment of the invention;

Fig. 5 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a fifth embodiment

of the invention;

Fig. 6 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a sixth embodiment of the invention;

Fig. 7 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a seventh embodiment of the invention;

Fig. 8 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as an eighth embodiment of the invention; and

Fig. 9 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a ninth embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0024] Hereunder, the preferred embodiments of the present invention will be described with reference to the accompanying drawings, in which Fig. 1 is a perspective view to typically illustrate an apparatus for generating compression waves in a conductive liquid as a first embodiment of the invention; Fig. 2 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a second embodiment of the invention; Fig. 3 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a third embodiment of the invention; Fig. 4 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a fourth embodiment of the invention; Fig. 5 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a fifth embodiment of the invention; Fig. 6 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a sixth embodiment of the invention; Fig. 7 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a seventh embodiment of the invention; Fig. 8 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as an eighth embodiment of the invention; and Fig. 9 an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as a ninth embodiment of the invention.

[0025] First, the first embodiment will be discussed. As shown in Fig. 1, the apparatus for generating compression waves comprises a vessel 2 containing a conductive liquid 1 (for example, molten metals, plastics, high-temperature liquid semiconductors, or ceramics, etc.), and an ac magnetic field generating electromagnetic coil 3 installed around the circumference of the vessel 2 as an ac electromagnetic force applying means, whereby a vertical ac magnetic field B_{AC} can be generated.

[0026] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, a frequency f of an ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by a frequency controller 5 within the range given by the [expression 1].

$$\frac{2}{L^2\pi\mu\sigma} \leq f \leq \frac{c^2\mu\sigma}{2\pi} \qquad \text{[expression 1]}$$

Here,

- f: frequency (a major frequency when a wave-form of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)
- L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
- μ: permeability of the conductive liquid
- σ: electric conductivity of the conductive liquid
- c: propagation velocity of the compression waves in the conductive liquid

[0027] The reason why the frequency f is set within the foregoing range is as follows. That is, the range where an electromagnetic force acts on a conductive liquid practically covers a depth from the surface, which is known as the depth of electromagnetic penetration. Provided that this depth of electromagnetic penetration is greater than the characteristic length L of the system, the electromagnetic force will not be generated efficiently. Therefore, to efficiently generate the compression waves, it is necessary to make the depth of electromagnetic penetration smaller than the characteristic length L of the system. This condition is given by the [expression 2].

$$\frac{2}{L^2\pi\mu\sigma} \leq f \qquad \text{[expression 2]}$$

[0028] On the other hand, a wavelength in a higher frequency region can be smaller than the depth of electromagnetic penetration. Under this condition, the compression waves cannot efficiently be generated. Therefore, to efficiently generate the compression waves, it is necessary to make the depth of electromagnetic penetration greater than the wavelength of the compression waves. This is given by the [expression 3].

$$f \leq \frac{c^2\mu\sigma}{2\pi} \qquad \text{[expression 3]}$$

[0029] In the foregoing apparatus for generating compression waves in a conductive liquid as the first embodiment, the ac frequency f of the ac electromagnetic force applying means that generates the compression waves in the conductive liquid 1 contained in the vessel 2 is set within an appropriate range by the aforementioned reason, and the compression waves can be generated with a sufficient strength accordingly. Thereby, degassing of the conductive liquid and micro structuring of the tissues are effectively processed, and material improvement after the solidification of the liquid will be brought about efficiently.

[0030] And, since the ac electromagnetic force applying means is installed around the circumference of the vessel 2 as the ac magnetic field generating electromagnetic coil 3, the generation of the compression waves in the conductive liquid contained in the vessel will be carried out with a simplified construction and a low cost.

[0031] Next, the apparatus for generating compression waves in a conductive liquid as the second embodiment of the invention will be described. As shown in Fig. 2, also in this embodiment, the apparatus comprises the vessel 2 containing the conductive liquid 1 (for example, molten metals or plastics, etc.), and the ac magnetic field generating electromagnetic coil 3 installed around the circumference of the vessel 2 as the ac electromagnetic force applying means, whereby the ac magnetic field B_{AC} can be generated vertically.

[0032] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0033] In this second embodiment, a dc magnetic field generating electromagnetic coil 6 is further installed so as to surround the circumference of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby a vertical dc magnetic field B_{DC} can be generated which passes through the conductive liquid 1.

[0034] In the second embodiment, the superimposition of the ac magnetic field generating electromagnetic coil 3 and the dc magnetic field generating electromagnetic coil 6 effects a still stronger generation of the compression waves in the conductive liquid 1 contained in the vessel 2. Thereby, improvement of the tissues after the solidification of the liquid and enhancement of the refining capabilities will sufficiently be accomplished.

[0035] Next, the apparatus for generating compression waves in a conductive liquid as the third embodiment of the invention will be described. As shown in Fig. 3, also in this embodiment, the apparatus comprises the vessel 2 containing the conductive liquid 1 (for example, molten metals or plastics, etc.), and the ac magnetic field generating electromagnetic coil 3 installed around the circumference of the vessel 2 as the ac electromagnetic force applying means, whereby the ac magnetic field B_{AC} can be generated vertically.

[0036] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0037] And, the dc magnetic field generating electromagnetic coil 6 is further installed so as to surround the circumference of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby the vertical dc magnetic field B_{DC} can be generated which passes through the conductive liquid 1. However, in this third embodiment, the dc magnetic field generating electromagnetic coil 6 is configured to function as a superconducting magnet by a cooling means 6a being a double cylindrical wall-formed container that contains a very low temperature liquid such as a liquefied helium to soak the electromagnetic coil 6. And, the vessel 2 containing the conductive liquid 1 and the ac magnetic field generating electromagnetic coil 3 are inserted in the bore of this superconducting magnet.

[0038] Thereby, the superimposition effect by the ac magnetic field generating electromagnetic coil 3 and the superconducting magnet 6, 6a generates more intensified compression waves in the conductive liquid 1, for example a molten iron, thereby leading to improvement of the material after the solidification of the liquid still more efficiently.

[0039] Next, the apparatus for generating compression waves in a conductive liquid as the fourth embodiment of the invention will be described. As shown in Fig. 4, the apparatus comprises the vessel 2 containing the conductive liquid 1 (for example, molten metals or plastics, etc.), and a pair of electrodes 7, 7 mounted on the circumferential wall of the vessel 2 as the ac electromagnetic force applying means, whereby an alternate current J_{AC} can be flown through the conductive liquid 1.

[0040] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 connected to the electrodes 7, 7 is set by the frequency controller 5 within the range given by the [expression 1].

[0041] Since the apparatus for generating compression waves in a conductive liquid as the fourth embodiment does not require the ac magnetic field generating electromagnetic coil, the total construction of the apparatus will be simplified remarkably. And in addition, the compression waves can be generated efficiently in the conductive liquid 1 contained in the vessel 2, by setting the frequency f of the applied alternate current within the range given by the [expression 1], based on the aforementioned reason; thus contributing to improvement of the material after solidification of the liquid 1.

[0042] In this embodiment, when the conductive liquid 1 is a high-temperature molten metal, the material of

the electrodes 7 is required to be resistant to a high temperature as well as being conductive, and the electrodes 7 are made up with, for example, ZrB_2 made of boron and zirconium.

[0043] Next, the fifth embodiment of the invention will be described. As shown in Fig. 5, the apparatus of this embodiment comprises, basically in the same manner as in the fourth embodiment, the vessel 2 containing the conductive liquid 1, and a pair of the electrodes 7, 7 mounted on the circumferential wall of the vessel 2 as the ac electromagnetic force applying means, whereby the alternate current J_{AC} can be flown through the conductive liquid 1.

[0044] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 connected to the electrodes 7, 7 is set by the frequency controller 5 within the range given by the [expression 1].

[0045] In this fifth embodiment, the dc magnetic field generating electromagnetic coil 6 is further installed so as to surround the circumference of the vessel 2, whereby the vertical dc magnetic field B_{DC} can be generated which passes through the conductive liquid 1.

[0046] Thus, according to the fifth embodiment, the superimposition of the alternate current J_{AC} flowing through the conductive liquid 1 and the vertical dc magnetic field B_{DC} effects a still stronger generation of the compression waves in the conductive liquid 1 contained in the vessel 2. Thereby, improvement of the tissues after the solidification of the conductive liquid 1 and enhancement of the refining capabilities will sufficiently be accomplished.

[0047] Further, in the sixth embodiment of the invention shown in Fig. 6, compared with the fifth embodiment in Fig. 5, the dc magnetic field generating electromagnetic coil 6 is configured to function as a superconducting magnet by the cooling means 6a being a double cylindrical wall-formed container that contains a very low temperature liquid such as a liquefied helium. And, the vessel 2 containing the conductive liquid 1 and provided with the eletrodes 7 is inserted in the bore of this superconducting magnet.

[0048] Thereby, the synergistic effect by the alternate current J_{AC} applied to the conductive liquid 1 and the dc magnetic field B_{DC} generated by the superconducting magnet 6, 6a generates more intensified compression waves in the conductive liquid 1, such as a molten iron, thereby achieving improvement of the material after the solidification of the conductive liquid 1 still more efficiently.

[0049] Next, the apparatus for generating compression waves in a conductive liquid as the seventh embodiment of the invention will be described. As shown in Fig. 7, the vessel 2 containing the conductive liquid 1 is formed of ceramics as magnesia (MgO), and a metal reinforcing material 8 (reinforcing metal plate in this embodiment) is applied to the circumference of the vessel 2.

[0050] Further, the ac magnetic field generating electromagnetic coil 3 as the ac electromagnetic force applying means is disposed overlying the vessel 2, so as to generate the vertical ac magnetic field B_{AC} efficiently without being influenced by the metal reinforcing material 8.

[0051] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0052] The apparatus for generating compression waves in a conductive liquid as the seventh embodiment, while the ceramic vessel 2 maintains a sufficient strength given by the metal reinforcing material 8, is able to generate intensified compression waves in the conductive liquid 1 without being influenced by the metal reinforcing material 8 by the ac magnetic field generating electromagnetic coil 3 disposed to overlie the vessel 2. Thus, material improvement after the solidification of the conductive liquid 1 will be accomplished by degassing of the conductive liquid 1 and micro structuring of the tissues.

[0053] Further, in addition to the magnesia having the melting point of 2800°C, the vessel 2 can employ as a material alumina (Al_2O_3, melting point 2080°C), silica (SiO_2, melting point 1710°C), or the like. For example, it is possible to contain a molten silica as a conductive liquid in a vessel made of a magnesia and apply a treatment to the liquid by means of the compression waves accordingly.

[0054] Next, the apparatus for generating compression waves in a conductive liquid as the eighth embodiment of the invention will be described. As shown in Fig. 8, the apparatus of this embodiment comprises, in the same manner as in the seventh embodiment, the ceramic vessel 2 with the metal reinforcing material 8, which contains the conductive liquid 1, and the ac magnetic field generating electromagnetic coil 3 overlying the vessel 2 as the ac electromagnetic force applying means, whereby the vertical ac magnetic field B_{AC} can be generated.

[0055] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0056] In this eighth embodiment, the dc magnetic field generating electromagnetic coil 6 is further installed so as to surround a part or the whole of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby the vertical dc magnetic field B_{DC} can be generated which passes inside the conductive liquid 1.

[0057] In the eighth embodiment, the superimposi-

tion of the ac magnetic field generating electromagnetic coil 3 and the dc magnetic field generating electromagnetic coil 6 effects a still stronger generation of the compression waves in the conductive liquid 1 contained in the vessel 2. Thereby, improvement of the tissues after the solidification of the conductive liquid 1 and enhancement of the refining capabilities will sufficiently be accomplished.

[0058] Further, in the same manner as the seventh embodiment, the strength of the ceramic vessel 2 for containing a high temperature conductive liquid 1 can be increased sufficiently by the metal reinforcing material 8, and since the ac magnetic field generating electromagnetic coil 3 is disposed overlying the vessel 2, the electromagnetic effect of the coil 3 cannot be influenced by the metal reinforcing material 8.

[0059] Next, the apparatus for generating compression waves in a conductive liquid as the ninth embodiment of the invention will be described. As shown in Fig. 9, the apparatus of this embodiment also comprises the ceramic vessel 2 with the metal reinforcing material 8, which contains the conductive liquid 1 (molten metals or plastics, etc.), and the ac magnetic field generating electromagnetic coil 3 overlying the vessel 2 as the ac electromagnetic force applying means, whereby the vertical ac magnetic field B_{AC} can be generated.

[0060] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0061] Further, the dc magnetic field generating electromagnetic coil 6 is installed so as to surround the circumference of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby the vertical dc magnetic field B_{DC} can be generated which passes inside the conductive liquid 1; however in the ninth embodiment, the dc magnetic field generating electromagnetic coil 6 is configured to function as a superconducting magnet by the cooling means 6a being a double cylindrical wall-formed container that contains a very low temperature liquid such as a liquefied helium to soak the electromagnetic coil 6. And, the vessel 2 containing the conductive liquid 1 and the ac magnetic field generating electromagnetic coil 3 are inserted in the bore of this superconducting magnet.

[0062] Thereby, the superimposition effect by the ac magnetic field generating electromagnetic coil 3 and the superconducting magnet 6, 6a generates more intensified compression waves in the conductive liquid 1, for example a molten iron, thereby leading to improvement of the material after the solidification of the conductive liquid 1 still more efficiently.

[0063] As the invention has been described in detail, the apparatus for generating compression waves in a conductive liquid according to the invention will achieve the following effects.

(1) Since the ac frequency of the ac electromagnetic force applying means that generates the compression waves in a conductive liquid contained in a vessel is set within an appropriate range, the compression waves can be generated with a sufficient strength, and thereby, degassing of the conductive liquid and micro structuring of the tissues are effected, and material improvement after the solidification of the conductive liquid is carried out efficiently.

(2) When the ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is installed around the circumference of the vessel, the compression waves are generated in the conductive liquid contained in the vessel with a simplified construction and a low cost.

(3) When, in addition to the ac magnetic field generating electromagnetic coil, a dc magnetic field generating electromagnetic coil is further installed around the circumference of the vessel, the superimposition of both the electromagnetic coils effects a stronger generation of the compression waves in the conductive liquid contained in the vessel, and thereby, enhancement of the refining capabilities of the conductive liquid and improvement of the tissues after the solidification of the liquid is sufficiently accomplished.

(4) When the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, and the vessel and the ac magnetic field generating electromagnetic coil are inserted in the bore of the superconducting magnet, the superimposition of both the dc magnetic field generating electromagnetic coil as the superconducting magnet and the ac magnetic field generating electromagnetic coil effects a still stronger generation of the compression waves in the conductive liquid contained in the vessel, and still more efficient improvement of the material after the solidification of the conductive liquid is achieved.

(5) When the ac electromagnetic force applying means is made up with a pair of electrodes that are installed at positions on a circumferential wall of the vessel facing to each other so as to energize the conductive liquid in the vessel and the ac power supply connected to the electrodes, and furthermore the dc magnetic field generating electromagnetic coil is installed around the circumference of the vessel, the ac magnetic field generating electromagnetic coil is not required; and accordingly, the total construction of the apparatus is simplified remarkably, and in addition, the compression waves is generated efficiently in the conductive liquid contained in the vessel so as to contribute to material improvement after the solidification of the liquid.

(6) Also in case of (5), when the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, in the bore of which is

inserted the vessel with the electrodes, the effect of a strong electromagnetic force by the dc magnetic field generating electromagnetic coil as the superconducting magnet is superimposed on the effect by the ac electromagnetic force applying mean by a pair of the electrodes, which generates the compression waves still more effectively in the conductive liquid contained in the vessel, and thereby material improvement after the solidification of the liquid is achieved.

(7) In case that the vessel is formed of ceramics resistant to a high temperature and reinforced by a metal reinforcing material on the circumference of the vessel, when the ac magnetic field generating electromagnetic coil is provided to overlie the vessel so that the electromagnetic effect of the coil is designed not to be influenced by the metal reinforcing material, it is possible to satisfy both the vessel maintaining a sufficient strength and a strong generation of the compression waves in the vessel.

(8) In case of (7), when an electromagnetic coil generating a strong dc magnetic field is provided around the circumference of the vessel, the superimposition effect by association with the ac magnetic field generating electromagnetic coil intensifies generation of the compression waves in the conductive liquid contained in the vessel, thereby improving the material after the solidification of the liquid more effectively.

(9) In case of (8), when the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, a still stronger generation of the compression waves in the conductive liquid contained in the vessel is effected, and an effective material improvement after the solidification of the liquid is accomplished more efficiently.

Claims

1. An apparatus for generating compression waves in a conductive liquid, comprising a vessel containing a conductive liquid and an ac electromagnetic force applying means that generates the compression waves in the conductive liquid contained in the vessel, wherein an ac frequency f of the ac electromagnetic force applying means is set within a range given by the following [expression 1]:

$$\frac{2}{L^2 \pi \mu \sigma} \leq f \leq \frac{c^2 \mu \sigma}{2\pi} \quad \text{[expression 1]}$$

here,

f: frequency (a major frequency when a waveform of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)

L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)

μ: permeability of the conductive liquid

σ: electric conductivity of the conductive liquid

c: propagation velocity of the compression waves in the conductive liquid.

2. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 1, wherein the ac electromagnetic force applying means is an ac magnetic field generating electromagnetic coil, which is provided around a circumference of the vessel.

3. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 2, wherein a dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel.

4. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 3, wherein the dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel and the ac magnetic field generating electromagnetic coil are inserted in a bore of the superconducting magnet.

5. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 1, wherein the ac electromagnetic force applying means comprises a pair of electrodes that are installed at positions on a circumferential wall of the vessel facing to each other so as to energize the conductive liquid, and an ac power supply connected to the electrodes.

6. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 5, wherein a dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel provided with the electrodes.

7. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 6, wherein the dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel with a pair of the electrodes is inserted in a bore of the superconducting magnet.

8. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 1, wherein the vessel is formed of ceramics and provided with a metal reinforcing material on the circumference thereof, and an ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is provided overlying the vessel.

9. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 8, wherein a dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel.

10. An apparatus for generating compression waves in a conductive liquid, as claimed in Claim 9, wherein the dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel is inserted in a bore of the superconducting magnet.

FIG. 1

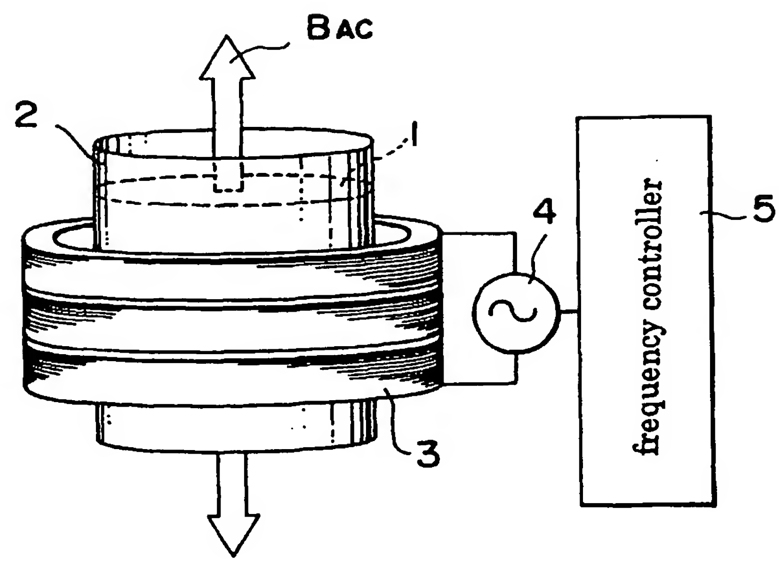


FIG. 2

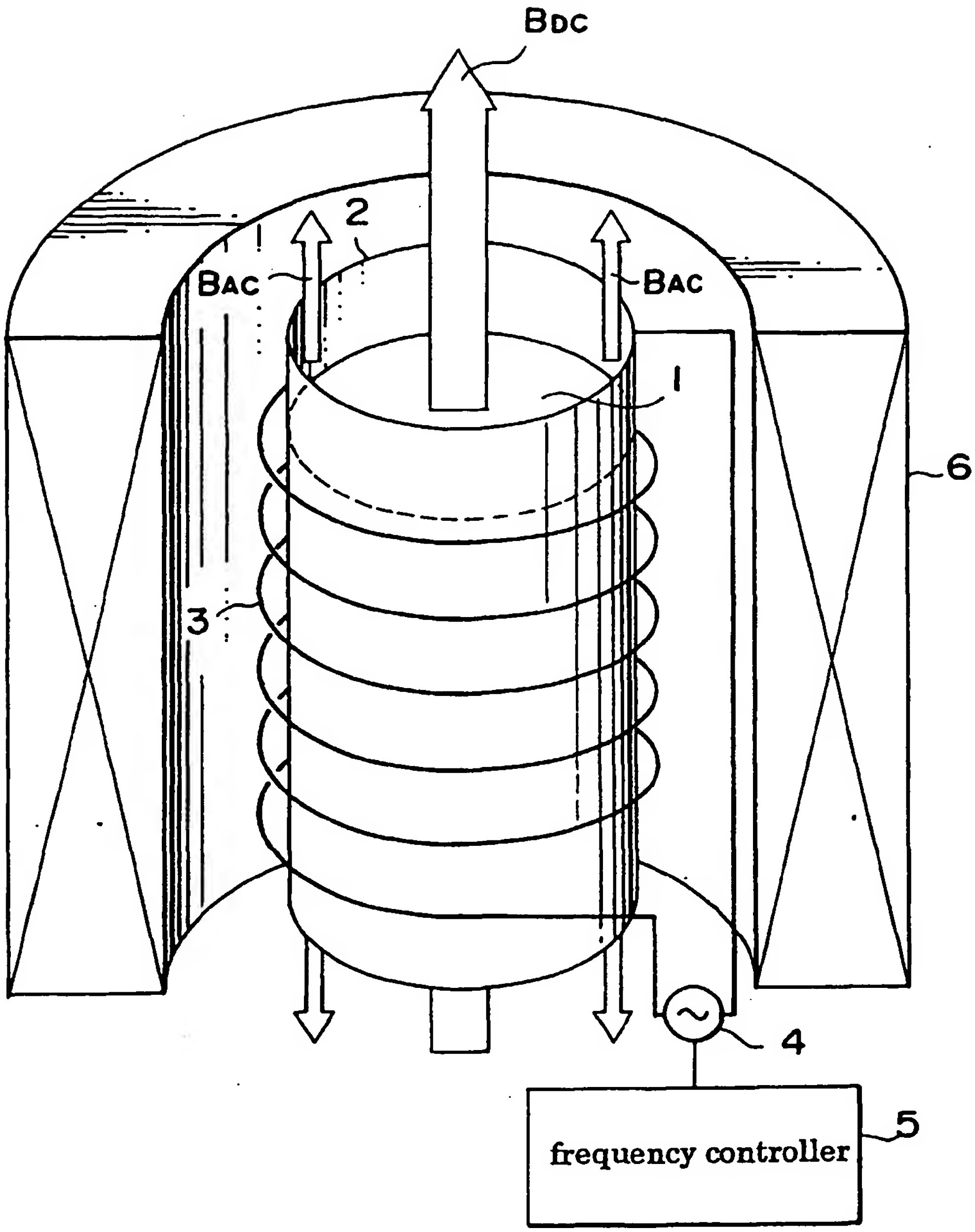


FIG. 3

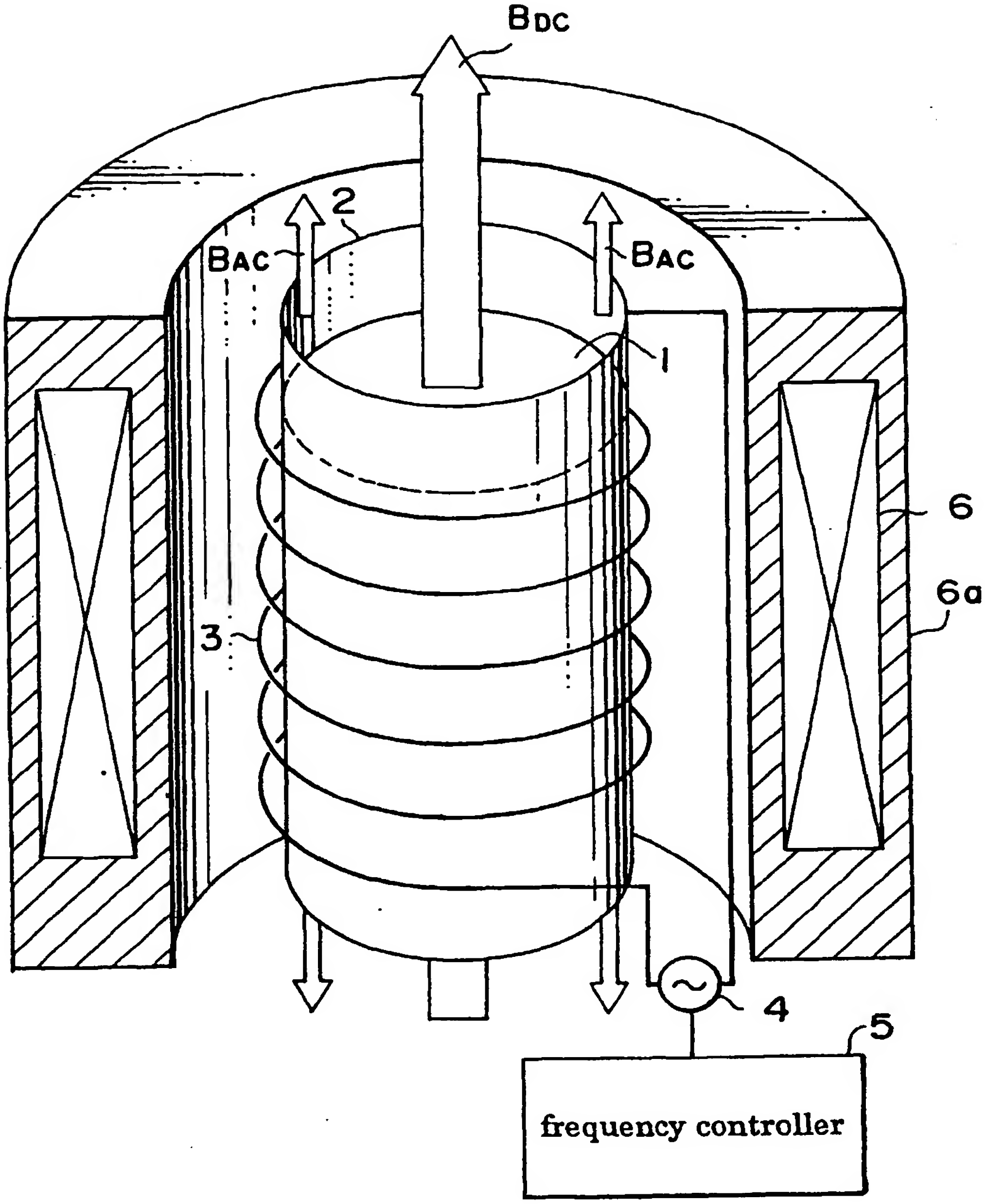


FIG. 4

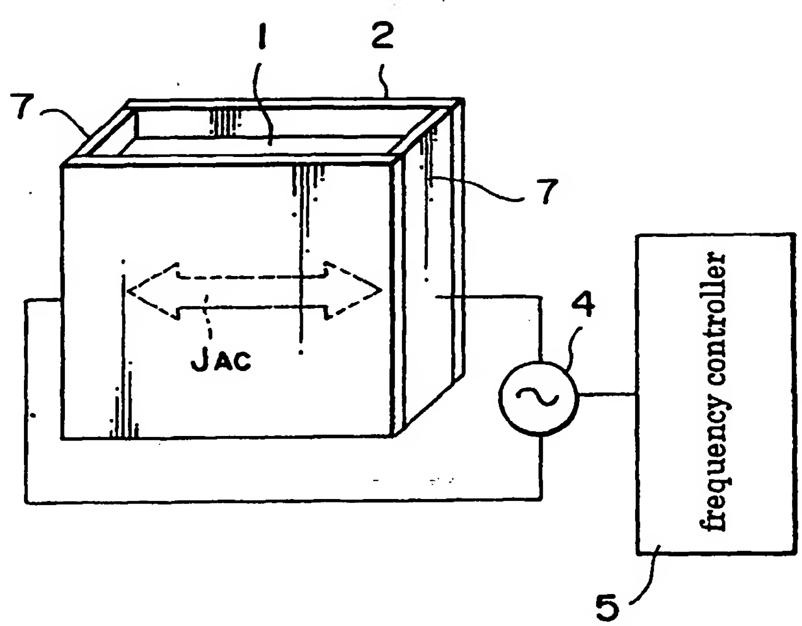


FIG. 5

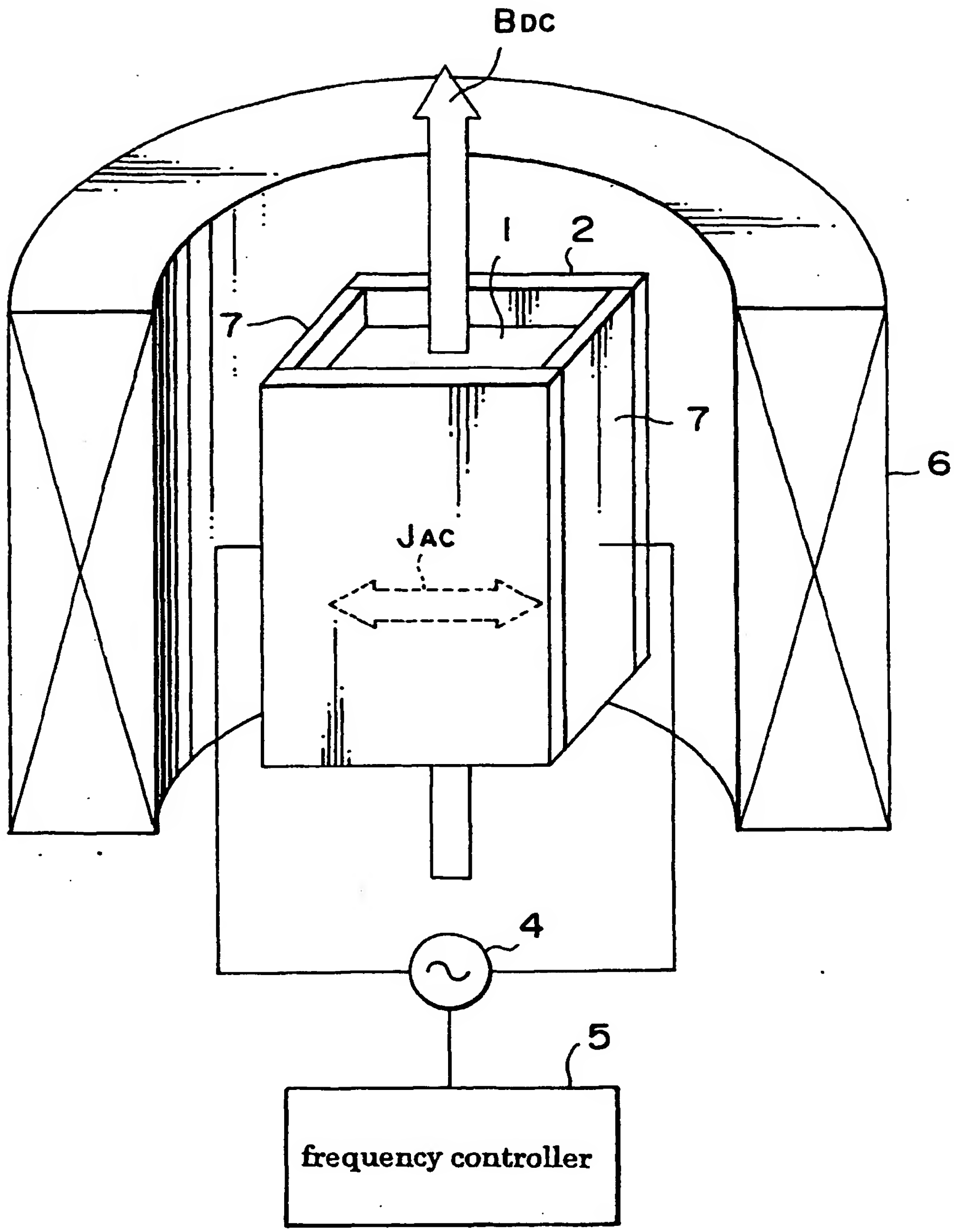


FIG. 6

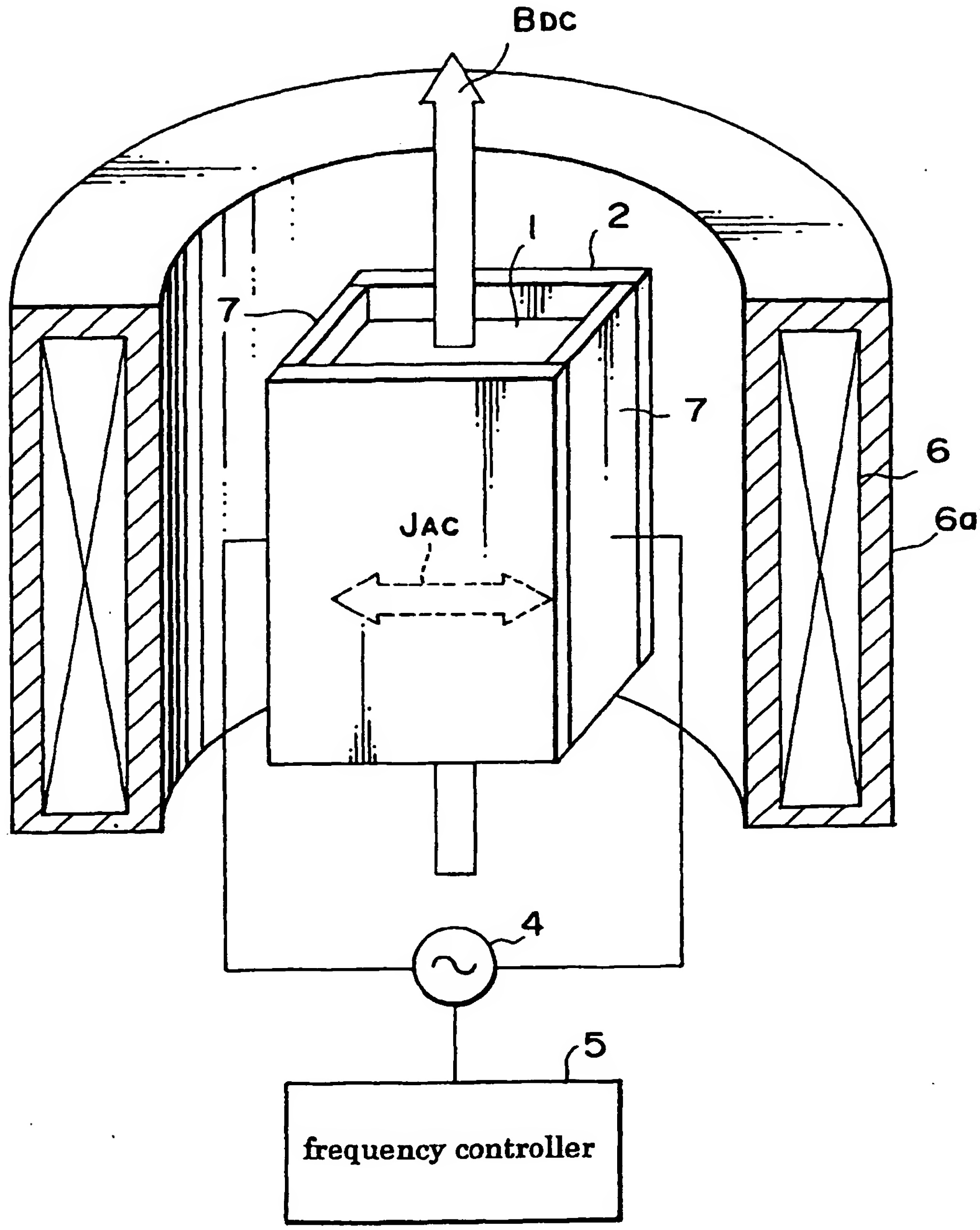


FIG. 7

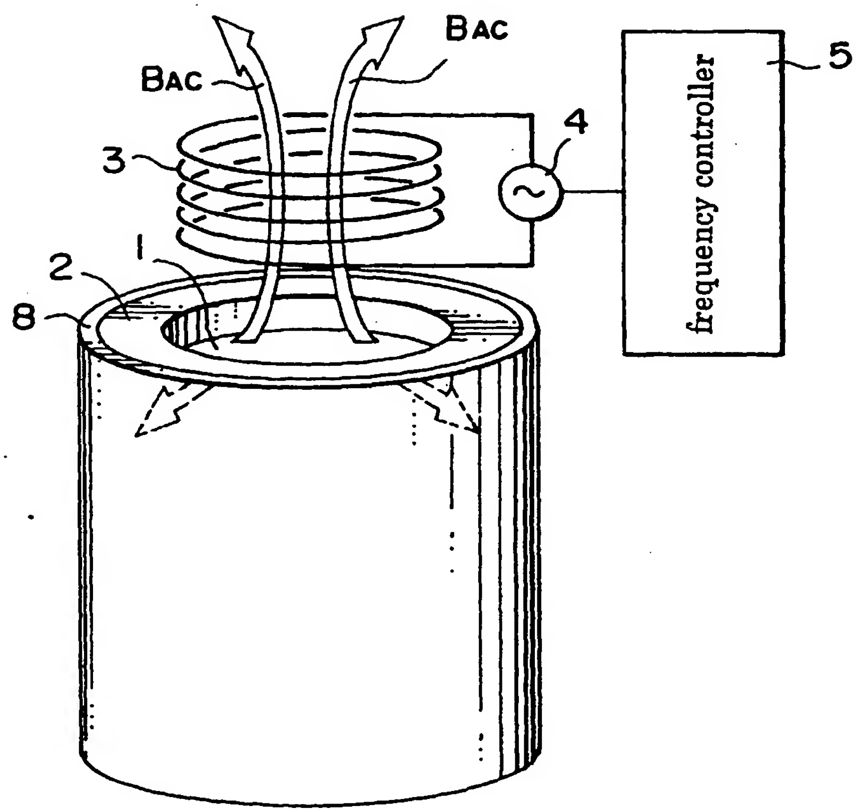


FIG. 8

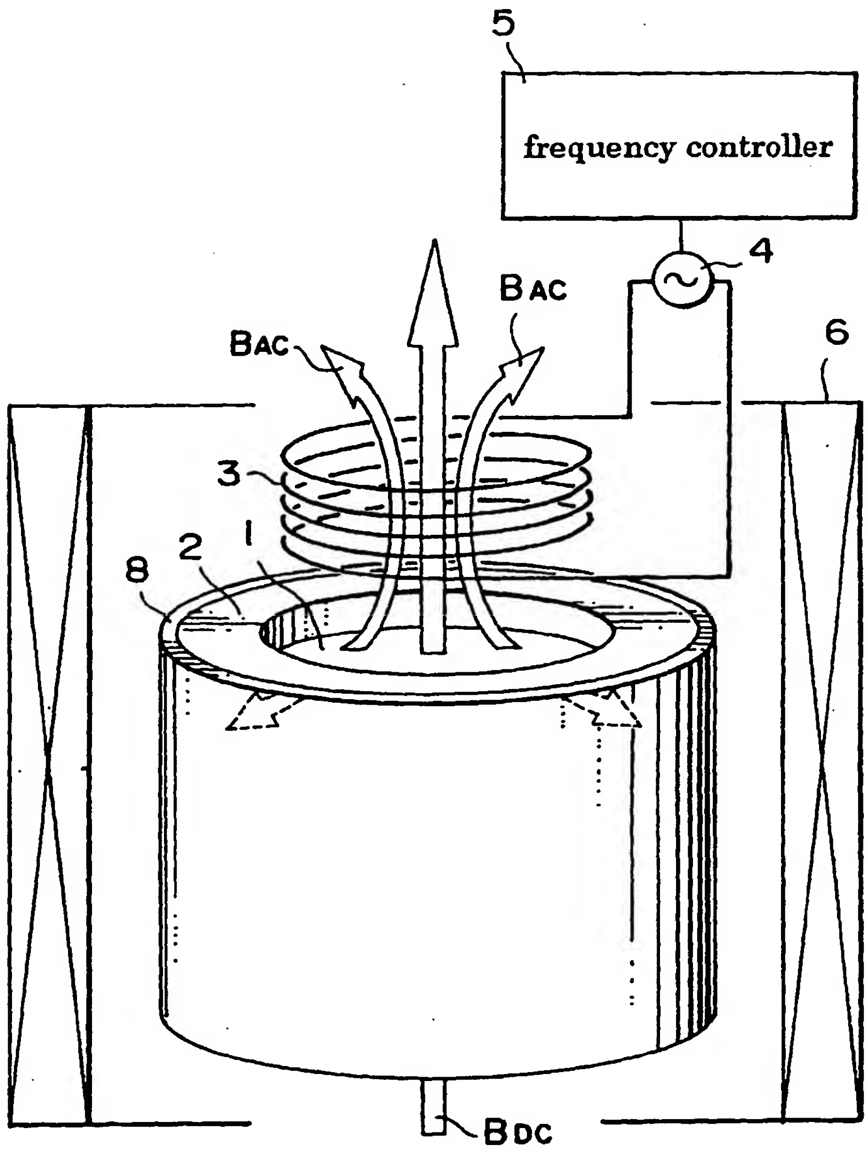
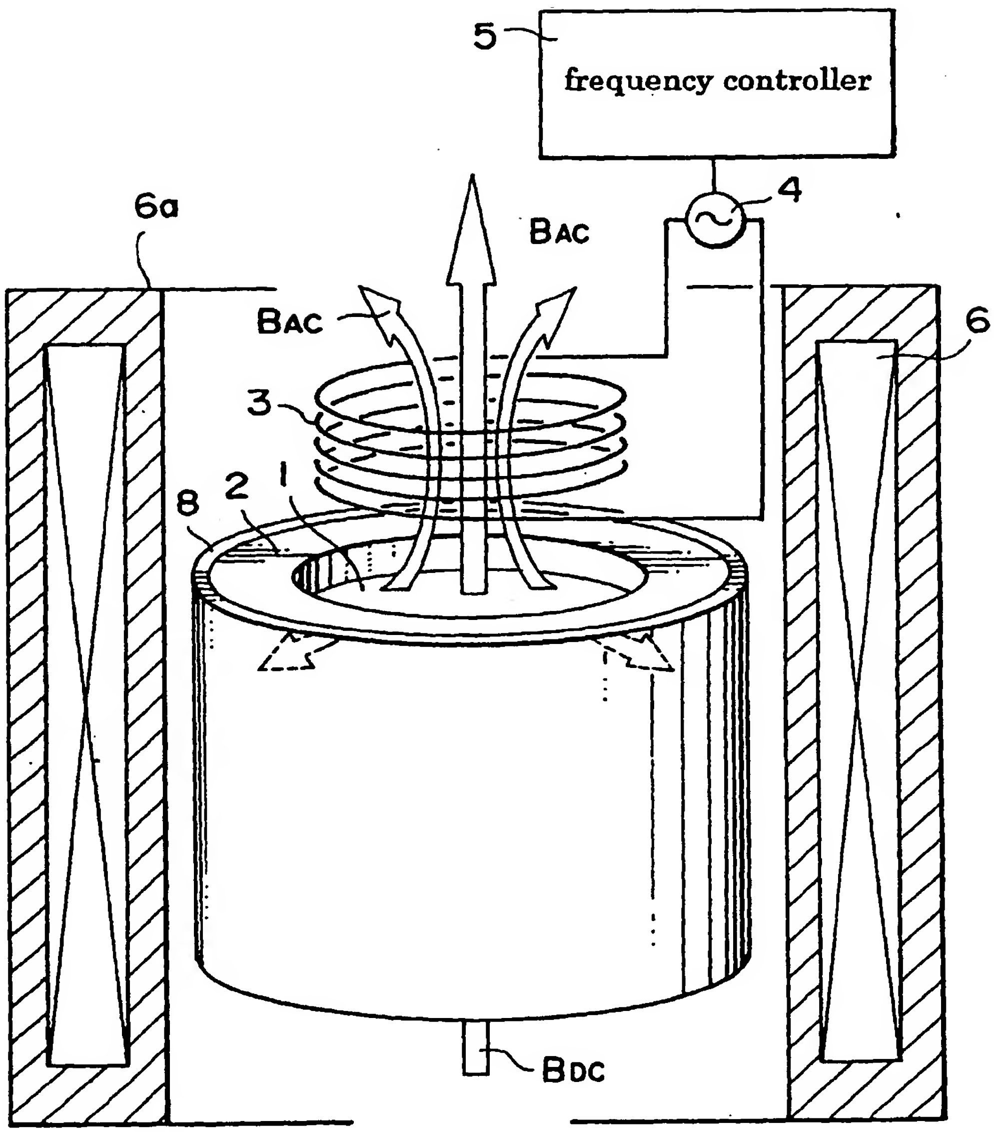


FIG. 9



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 10 9245

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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A	EP 0 539 666 A (INLAND STEEL CO) 5 May 1993 (1993-05-05) * page 3, line 1 - page 5, line 53 * * claims 1-4,6,7,9-11,13,14; figures 1-5 * ---	1-3	
A	FR 2 556 251 A (VIVES CHARLES) 14 June 1985 (1985-06-14) * page 1, line 35 - page 2, line 14 * * claims * ---	1	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 January 2001	Ceulemans, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 10 9245

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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